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Selection of **PUMPING EQUIPMENT**

for Irrigation



AGRICULTURAL EXTENSION SERVICE

**SOUTH DAKOTA STATE COLLEGE
U. S. DEPARTMENT OF AGRICULTURE**

BROOKINGS, SOUTH DAKOTA

Selection of Pumping Equipment For Irrigation

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A correctly designed pump irrigation installation, used under proper conditions and with good management, can be a profitable practice in most parts of South Dakota. It is the intention of this publication to briefly discuss the equipment that goes into a pumping plant. By so doing, potential users of this equipment will have some indication of the operating costs of the various units as well as the type of equipment that is best suited to his particular conditions.

The equipment, however, is just one phase in developing a pump irrigation system. Irrigation should be attempted only where both the soil and water are found to be suitable. The following are questions that should be answered before any equipment is purchased:

- Is the soil adapted to sustained irrigation?
- Is the quality of the water acceptable?
- Is there enough water for irrigation especially at the time of the year when it is needed the most?
- Is the type of water supply such that permission is required from the State Engineer's office before it can be utilized for irrigation?

The answers to these questions are not always clear-cut. Technical assistance should be obtained to aid in the overall planning of a pump irrigation system.

If all conditions are found to be satisfactory for irrigation and the equip-

ment is properly selected and laid out, there is still no assurance that irrigation will be a success. Soil-building practices should accompany irrigation since the food supply in the soils is removed at a rate faster than under dry-land farming. Selecting the method of irrigation that best fits the conditions, determining the amount, rate and time to apply water, are other factors that should be taken into consideration in order to obtain the maximum net benefits from irrigation.

Capacity Required

The basis for estimating the pump capacity needed to irrigate a particular field is the daily soil moisture requirement of the crops. As a general average, most crops in South Dakota use about 0.2 inches of water per day. Thus, for a 40-acre field, approximately 0.2×40 equals 8 acre-inches of moisture which is consumed during a 24-hour period. On an hourly basis, this would mean that one-third of an acre-inch of water per hour is being used by the crops. Pumping at the rate of 450 gallons per minute will deliver one acre-inch of water per hour. Thus, for a water requirement of one-third of an acre-inch per hour, a flow of $\frac{1}{3} \times 450$ or 150 gallons per minute is needed.

Two adjustments to this figure, however, have to be made. In the first instance, we have assumed a 24-hour day of pumping. In most cases, this is not

Table 1. Quantity of Water*, in Gallons per Minute Required to Irrigate a Given Acreage

Acres To Be Irrigated	Hours of Pumping per Day						
	10	12	14	16	18	20	22
10	150	125	110	95	85	75	70
20	300	250	215	190	170	150	135
30	450	375	320	280	250	225	205
40	600	500	430	375	335	300	270
50	750	625	540	470	425	375	340
60	900	750	645	565	500	450	410
80	1200	1000	860	750	670	600	545
100	1500	1250	1075	940	835	750	685
120	1800	1500	1285	1125	1000	900	820
150	2250	1875	1610	1410	1250	1125	1005
200	3000	2500	2150	1875	1670	1500	1365

*Based on crops requiring 0.2 inches of moisture per day and on an irrigation efficiency of 60 percent.

Table 2. Horsepower* Required to Operate Pump at Various Capacities and Lifts

Pump Capacity Gallons per Minute	For Gravity Discharge and Lifts of-					For 50 Psi Discharge for Sprinklers and Lifts of-				
	10 ft.	20 ft.	40 ft.	60 ft.	80 ft.	10 ft.	20 ft.	40 ft.	60 ft.	80 ft.
100	0.4	0.8	1.6	2.4	3.1	4.9	5.3	6.1	6.8	7.6
200	0.8	1.6	3.1	4.7	6.2	10	11	12	14	15
300	1.2	2.4	4.7	7.0	9.4	15	16	19	21	23
400	1.6	3.1	6.2	9.4	12.5	20	21	25	27	31
500	2.0	3.9	7.8	11.7	15.6	25	27	31	34	39
600	2.4	4.7	9.4	14.0	18.7	30	32	37	42	46
800	3.1	6.2	12.5	18.7	25.0	39	42	49	54	61
1000	3.9	7.8	15.6	23.4	31.2	49	53	61	68	76
1200	4.7	9.4	18.7	28.1	37.4	59	64	73	82	91
1500	5.9	11.7	23.4	35.1	46.8	74	80	92	102	114

*Based on estimated pumping plant efficiency of 65 percent.

practical. Let us assume a 16-hour pumping day. Since for a 40-acre field, 8 acre-inches of moisture is used in a day, a flow equal to 8/16 or ½ acre-inch per hour would be required. This represents a pump discharge requirement of ½ x 450 or 225 gallons per minute.

The next adjustment concerns the efficiency of irrigation. It has been assumed that all the water applied will be used by the crop. This is never true. Regardless of the method of irrigation some of the water applied will be lost in evaporation, in deep penetration beyond the root zone of the crop, or in run-off. To compensate for these losses, a larger flow of water is required. For design purposes, an irrigation efficiency of 60 per cent can be assumed. In

many instances, this figure will be exceeded.

To continue the above example, the final figure for estimating the pump capacity needed to irrigate 40 acres, pumping 16 hours a day, at an irrigation efficiency of 60 per cent, is 225/.60 or 375 gallons per minute.

Based on crops using 0.2 inches of water per day and on an irrigation efficiency of 60 per cent, Table 1 can be used to estimate the quantity of water required to irrigate a given acreage.

Power Required

The actual power required to operate a pump is known as the brake horsepower. To determine this figure,

it is necessary to know the quantity of water that will be pumped, the total head or pressure against which it will be pumped, and the efficiency of the pumping unit.

The total head usually expressed in feet of water, consists of the following factors:

1. **Suction lift (vertical distance in feet from water level in well to center line of pump, drawdown included).**
2. **Difference in elevation from pump center line to point of discharge.**
3. **Friction loss in pipe and fittings.**
4. **Discharge pressure.**

The values for friction losses and discharge pressures can be obtained from sprinkler irrigation companies. When pumping from surface water supplies, the suction lift is readily ob-

tainable. In the case of pumping from wells, the well driller should furnish this information.

Manufacturers of pumping equipment can supply the user with the efficiency of their units. For estimation purposes, a figure of 65 per cent is often used.

Table 2 can be used to estimate horsepower requirements. It is based on a pumping plant efficiency of 65 per cent. The left-hand side of the table is for gravity irrigation while the right side can be used to estimate the power required to operate a sprinkler system. The table is based on the following formula:

$$\text{BHP} = \frac{\text{GPM} \times \text{total head in feet}}{3960 \times \text{pumping plant efficiency}}$$

Pumps

Irrigation pumps usually are either of the horizontal centrifugal type or the deep-well turbine type. In most cases, there is no choice in their selection. That is, deep-well turbine pumps are used in practically all well installations and centrifugal pumps are used to pump water from surface water sources such as streams, lakes, and stock-water reservoirs. However, where the pumping level of the water in a well is close to the ground surface, centrifugal pumps are sometimes used. The main reason for their use is that centrifugal pumps have a substantially lower initial cost and a longer life than do turbine pumps. As a general rule, the maximum practical suction lift, or the vertical distance between the water surface and the pump, for a centrifugal pump is about 15 feet. It is important that the suction lift includes the drawdown within the well when the water is

being pumped at the required rate. The drawdown generally increases as the pumping rate increases. Sometimes pits are dug to reduce the suction lift so that a centrifugal pump can be used.

Centrifugal Pumps

Centrifugal pumps have to be primed before they will pump water. That is, they will not lift water unless the pump casing and suction line are both filled with water. The pump can be damaged if it loses its prime and continues to run. Thus, it is advisable to install a pressure switch to shut off the power unit in the event the pump loses its prime.

There are several methods of priming a centrifugal pump. One method used in connection with internal combustion engines is by a device called an exhaust primer. The exhaust primer accomplishes its job by means of a rapidly-moving jet of engine exhaust gas.

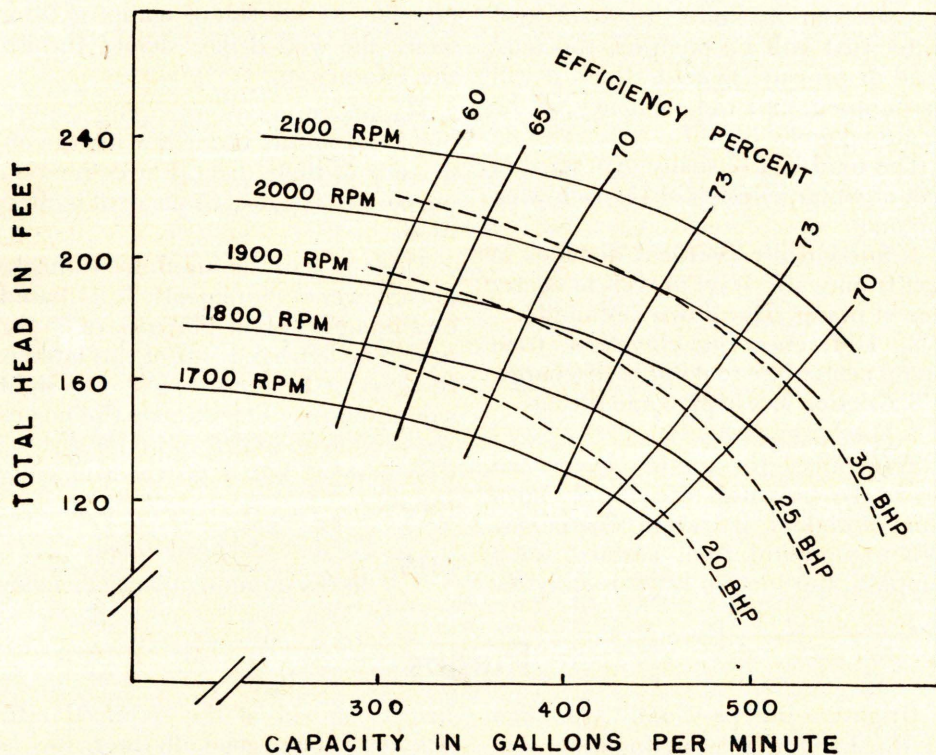


Fig. 1. Performance curves of a centrifugal pump

Centrifugal pumps can also be primed by using a foot valve placed at the end of the suction line and installing a gate valve in the discharge line. With the discharge valve closed, the suction line and pump casing are filled with water usually from an overhead tank or by using a hand pump located on top of the pump casing.

Even though centrifugal pumps run at a high efficiency over a relatively wide range of operating conditions, each pump has a certain head and discharge where it operates the most efficiently. If the head is either decreased or increased from this value, the efficiency will drop. Thus, in selecting a pump, the operating head, discharge requirements, and the lowest acceptable pump efficiency should be speci-

fied. In the larger pumps, pump efficiencies of between 70 and 75 per cent are readily obtained. These figures are somewhat high for the smaller pumps. In buying a second-hand pump, the operating efficiency should be known. While the initial cost may be low this saving may be more than eaten up by a high operating cost due to a low pump efficiency. Reducing the pump efficiency in half will nearly double the operating cost.

A typical set of performance curves for a centrifugal pump is shown in Fig. 1. This pump was selected to deliver 450 gallons per minute against a total head of 160 feet. The curves also indicate that 25 horsepower will be required to run the pump.

The size of a centrifugal pump is

commonly designated by the size of the discharge opening. Since friction loss in the intake line reduces the allowable suction lift, the intake fitting on the pump is often larger than the discharge fitting.

Deep-Well Turbine Pumps

All types of pumps that are suspended by the discharge column, within which the drive shaft is located, are occasionally grouped under the heading

of turbine pumps. Other pumps that are sometimes included in this classification are propeller, or screw pumps, and mixed-flow pumps. These pumps are designed to pump large quantities of water against low heads. In irrigation work turbine pumps are commonly called "deep-well turbines" because of their adaptability in pumping from deep wells. An electrically driven deep-well turbine installation is shown in Fig. 2.

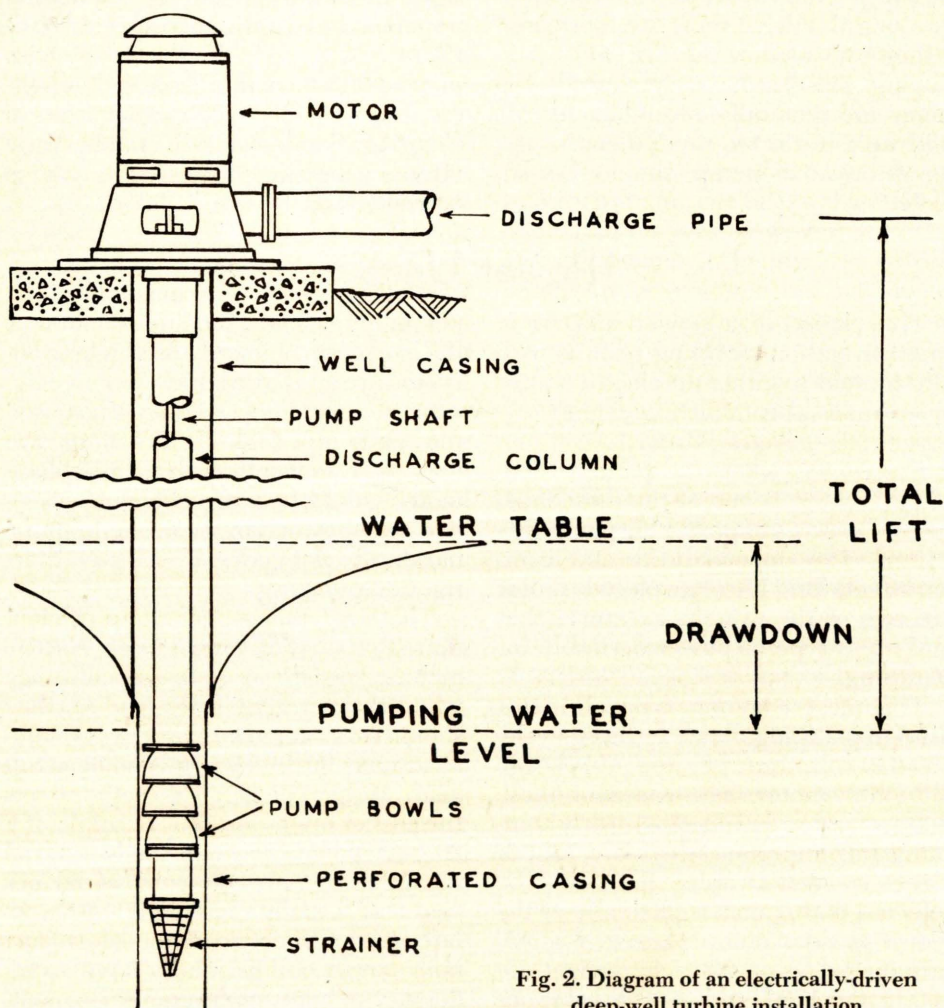


Fig. 2. Diagram of an electrically-driven deep-well turbine installation

For deep wells, or where additional pressure is required such as to operate sprinklers, more than one impeller or stage, may be needed. The impellers are housed in units called bowls and are placed one atop another. Inasmuch as the bowls are placed below the water level representing the lowest draw-down in the well, turbine pumps do not have to be primed.

The unit that supplies the power to the pump is located at the surface. The bearings which are found intermittently along the drive shaft are lubricated either by water or oil. For wells producing fine sand, oil-lubricated turbines are generally recommended. If oil-free water is required, then the water lubricated pump should be selected.

The performance characteristics of turbine pumps are very similar to those of centrifugal pumps since they both operate under the centrifugal principle. Turbines, however, cannot operate at a high efficiency over as wide a range of conditions as can centrifugal pumps.

Turbine impellers like those in most centrifugal pumps used for irrigation, are either enclosed or semi-enclosed. Enclosed impellers have discs on both sides of the vanes while semi-enclosed impellers have a disc on one side with the other side open. Higher efficiencies may be obtained with enclosed impellers, but they are more susceptible to clogging. Semi-enclosed impellers are often recommended where fine sand is encountered.

Power Units

The choice of a power unit for a small irrigation pumping plant is usually limited to either an electric motor or an internal combustion engine.

Electric Motor

Electricity, when available at reasonable rates, is one of the most satisfactory sources of power for pump irrigation. The dependability and comparatively long life of an electric motor are two of the principal features that make this type of power desirable for pumping.

The most common type of motor used in pumping plants is the 60-cycle, 220-440 volt, three phase, squirrel cage induction motor. The speed of these motors under full load is nearly constant. It is important, therefore, that in direct connected units, the pump be selected that operates efficiently at the motor speed. Common speeds for motors operating on 60-cycle current are 860, 1160, 1760, and 3500 revolutions

per minute. The 1760-speed motor is the one most commonly used where 60-cycle current is available.

Single-phase motors are often used for loads up to and including five horsepower even though a three-phase motor would be more efficient. Above five horsepower, however, single-phase motors are not generally adapted to irrigation pumping.

The large motors are more efficient than the smaller ones. Since electric motors operate at a lower efficiency when they are not fully loaded, they should be selected so that they operate at around 90 to 95 per cent of a full load. Motor efficiency directly affects the cost of operation. For example, if a 20 horsepower motor is delivering its rated load at an efficiency of 90 per cent it is actually drawing 20/.90 or 22 horsepower. Electric motors above five horsepower will generally have an efficiency of between 88 and 90 per cent.

Most squirrel cage induction motors will operate satisfactorily under a continuous overload of 10 per cent. In rare instances it may be more economical to slightly overload a motor than to install the next larger size. However, since overloading causes heating which tends to shorten the life of a motor, this practice is not recommended.

Electric motors should always be provided with protection against excessive heating due to overloading or undervoltage. In addition, the larger motors will require a starting compensator. It is advisable to check with the power supplier in the use of these motor controls and protective devices.

Standard motor sizes above five horsepower for three phase power are 7½, 10, 15, 20, 25, 30, 40, and 50 horsepower.

Internal Combustion Engines

Gasoline engines are by far the most common source of power for irrigation pumping units in South Dakota. In many cases, however, the selection of another type of engine may be more economical in the long run. Other engines being considered or used to a limited extent in this state are Diesel engines and propane-burning engines.

For a given set of conditions, the selection of the most suitable engine depends on such factors as the local cost of fuel, initial cost of the engine, the maintenance required for constant operation, and the length of time the engine is operated during the year.

Gasoline engines have two principal advantages over Diesel engines. They have a lower first cost and maintenance service is more readily available. On the other hand, Diesel engines operate at a higher efficiency resulting in a lower fuel cost and they have a longer engine life. The decision between gasoline and Diesel engine depends mainly

on the average number of hours the pumping plant will be in operation each year and on the size of the engine. Thus, in areas where a limited amount of irrigation is practiced, Diesel engines may not be justified. This may also be true for the smaller pumping plants. As a rough guide, if an engine with a rating of at least 20 horsepower is to run more than 800 hours per year, serious consideration should be given to using Diesel engines rather than gasoline engines, as the source of power for pumping.

In some areas, the use of propane as a fuel may be more economical when compared to other fuels. Gasoline engines can be converted to burn propane, or engines designed specifically to burn propane can be purchased. The converted engines, however, are often low in efficiency. The first cost of propane-burning engines and accessories may run \$400 higher than gasoline engines. While engines using propane will burn more fuel than engines using gasoline for a similar job, the cost differential in the fuels may be such so as to justify the use of propane. The cost of operating propane engines will be approximately the same as that for gasoline engines if propane can be bought for around two-thirds to three-fourths the price of gasoline.

In many instances farmers are using their tractors as a source of power. An advantage of this practice is that only a small part of the depreciation would have to be charged against the cost of pumping. Oftentimes, however, the tractor has more power than is needed. In the case of gasoline engines, this would decrease the efficiency of the power unit since the engine is not operating under its rated load. It is also likely that the tractor will be required for other farm work. Thus, if at all pos-



Fig. 3. Portable centrifugal pumping unit powered by a gasoline engine
(Note hose lines that are used for applying soluble fertilizers through the irrigation system)

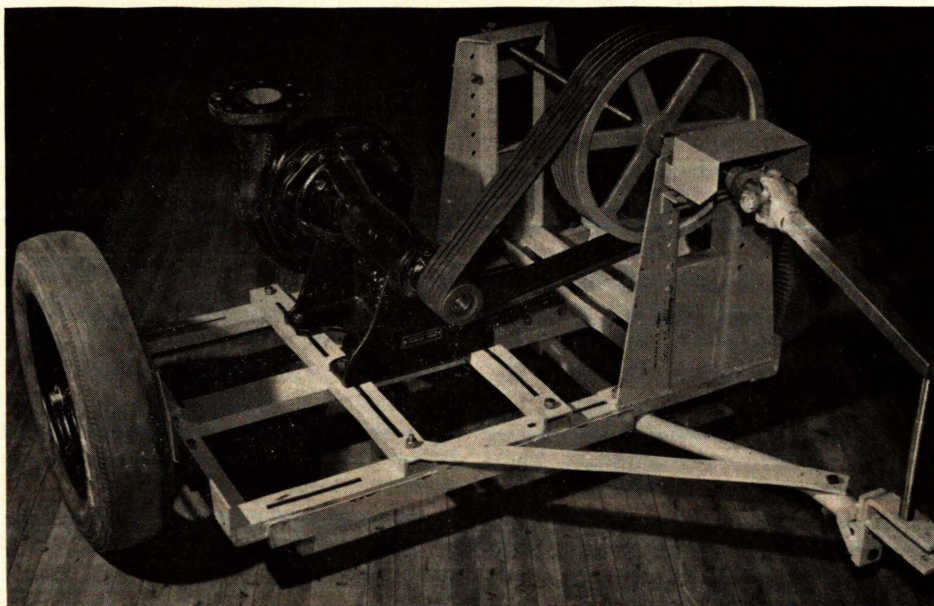


Fig. 4. A trailer-mounted centrifugal pump that is operated from the power take-off of a tractor

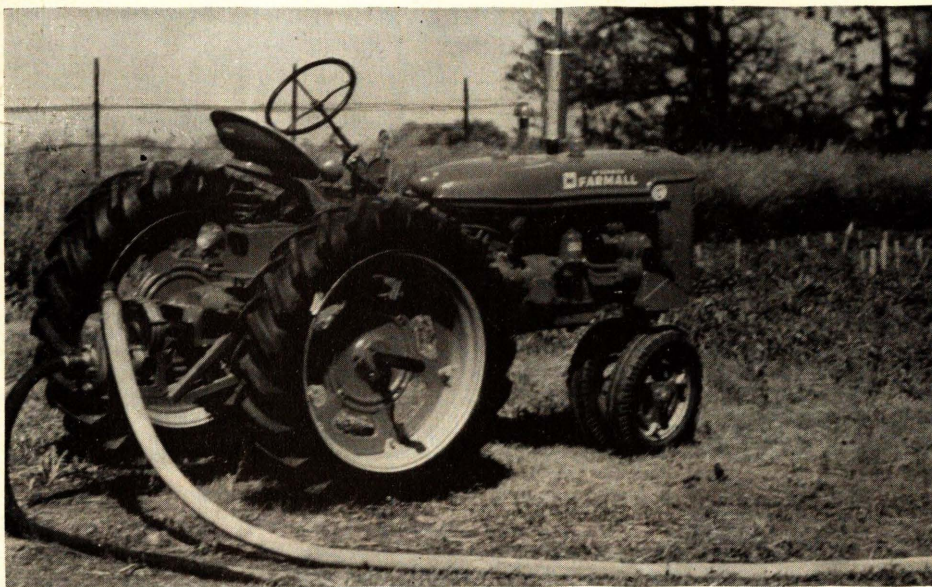


Fig. 5. A centrifugal pump mounted on the rear end of a tractor operated from the tractor's power take-off

sible, it is recommended that irrigation systems have their own sources of power.

In selecting an engine for a particular job, the continuous service rating rather than the maximum rating should be used. Overloading will result in reduced engine life while underloading will cause excessive fuel consumption. The engine should be loaded to about 75 or 80 per cent of its rated power. These figures may be somewhat conservative for Diesel engine. For pumping at the higher altitudes or where higher temperatures are en-

countered, a still greater horsepower reserve should be allowed. A general rule for correcting for elevation and temperature is to reduce the continuous service rating 3 per cent for every 1000 feet above 3000 feet and one per cent for every 10° F. above 60° F. In all cases, manufacturer's recommendations should be followed. As an example, if the pumping load requires 20 horsepower and the continuous service factor is 80 per cent, the gasoline engine selected should be rated at $20/.80$ or 25 horsepower. Used engines probably should not be loaded to more than 50 to 60 per cent of their rated power.

Drives

Centrifugal pumps are generally direct-connected to the power unit. Figure 3 illustrates a portable pumping unit powered by a gasoline engine. In

the event a tractor is the source of power, several methods may be used to run the pump. These are shown in Figures 4, 5, and 6. In the first two methods, the

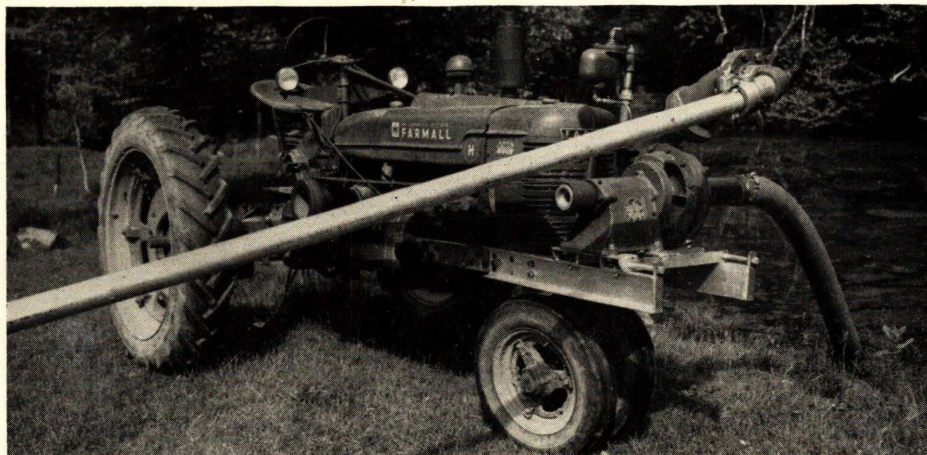


Fig. 6. A tractor-mounted, belt-driven centrifugal pump

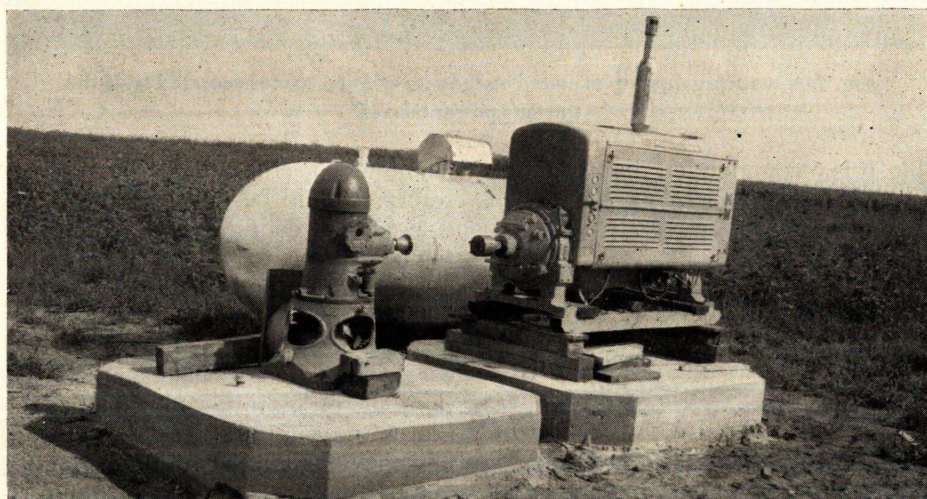


Fig. 7. A turbine pump installation, not quite completed, using a right angle gear drive

power-take-off is used, while in the latter method the pump is run from the belt of the tractor.

Turbine pumps may be direct-driven, belt-driven, or driven through a 90 degree gear head. For electrical installations, the direct connection is the cheapest and most efficient type of drive. In installations where the water

level varies within wide limits, it may prove economical to use a variable-speed motor. These motors, however, are more expensive than constant-speed motors. Since most units have constant-speed electric motors, the discharge of the pump cannot be changed, and thus extreme care should be taken in selecting a pump.

The right angle gear drive (see Fig. 7) is the most dependable and efficient method of transmitting the power of a combustion engine to a turbine pump. The units are made in a variety of gear ratios to allow the pump and engine to operate at their most efficient speeds. A shaft with double universal joints, to take care of any changes or errors in alignment of pump and engine, is recommended to connect the engine to the gear head.

Belt drives, either flat-belt or V-belt, are cheaper than gear drives but are not as efficient. The efficiency of the various drives compare as follows: gear head—95 per cent or more, V-belt—90 to 95 per cent, flat-belt—85 to 90 per cent. A V-belt installation is slightly higher in cost than one using a flat-belt.

An added advantage of V-belts, however, is that they can operate with the pulley centers much closer together than is permissible for flat-belts. Thus, they can be used in confined spaces. The recommendations of the manufacturer should be followed in selecting the size of the V-belt, number of belts, and pulley diameters.

Fig. 8 shows a flat-belt drive head while Fig. 9 illustrates a combination electrically-driven and flat-belt drive head for turbine pumps. The latter unit can be used where it is anticipated that electric power will become available in the near future.

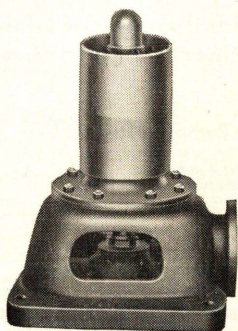


Fig. 8. Flat belt drive head for deep-well turbine pump

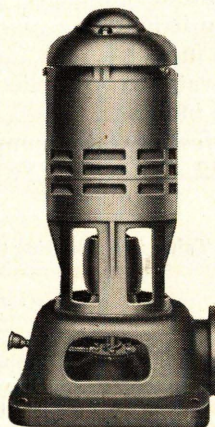


Fig. 9. Combination electrically-driven and flat-belt drive head for deep-well turbine pump

Estimated Cost of Pumping

The yearly cost of pumping water may be divided into two groups: fixed costs and operating costs. The items that make up each group are as follows:

Fixed Costs

Depreciation
Interest on investment
Taxes and insurance

Operating Costs

Fuel or power
Lubrication
Repairs
Labor

An important point to keep in mind is that regardless whether or not water is pumped, fixed costs continue each year. In other words, the fixed cost per acre-foot of water pumped will decrease as the number of acre-feet pumped per year increases. Table 3 can be used to estimate these costs for installations with various power units

for both centrifugal and turbine pumping plants.

Operating costs will vary with the pump efficiency, total head, cost of fuel or power, and attention given the pumping plant. An estimate of the operating cost of a well-designed pumping plant operating under good conditions can be made by using Table 4. The figures in this table, as well as those in Table 3, are not exact and should be used as a guide only.

Thus, through the use of Tables 3 and 4, the approximate annual cost of pumping a given quantity of water can be estimated. The following example will illustrate this method:

Acres to be irrigated.....	80
Total head in feet.....	60
Irrigation water to be applied per acre, inches.....	15
Total acre-feet of water pumped, 80 x 15/12.....	100

Initial cost of deep-well turbine installation:

Well and casing.....	\$1500
Deep-well turbine pump.....	1200
Gasoline engine.....	800
Right angle gear drive.....	400
Total.....	\$3900

Annual Cost of Pumping:

Fixed cost	
12% of \$3900.....	\$468
Operating Cost	
Per acre-foot = $\$0.05\frac{1}{2} \times 60 =$ \$3.30	
Total = 100 x \$3.30.....	\$330
Total.....	\$798
or about \$10 per acre	

To find the total cost of irrigation, the cost for distributing the water together with the cost for labor must be added to this cost of pumping.

Table 3. Estimating the Annual Fixed Cost of a Pumping Installation

Type of Power Unit	Annual Fixed Costs Expressed as Percentage of Initial Cost
Gasoline	12
Propane	10
Diesel	10
Electric	8½

Table 4. Estimating the Cost of Operating a Pumping Installation

Type of Power Unit	Unit Cost for Fuel or Power	Operating Cost* per Acre-Foot of Water Pumped per Foot of Total Head
Gasoline.....	\$0.20 per gal.	5½c
Propane.....	.12 per gal.	4c
Diesel.....	.15 per gal.	3c
Electric†.....	.02 per KWH	3½c

*Includes cost for fuel or power, lubrication and repairs but not for labor.

†Does not include demand or minimum charges.

Summary

1. Determine rate of flow of water required for irrigation.

2. Determine total head required.

3. Select pump with a high efficiency by using pump performance curves that meet discharge and total head requirements. In the case of direct connected units, pump speed is an added factor in making selection.

4. Determine brake horsepower required to operate pump either from pump performance curves or by using the following formula:

$$\text{BHP} = \frac{\text{GPM} \times \text{total head in feet}}{3960 \times \text{pump efficiency}}$$

5. When pump and power unit are not direct connected, correct brake

horsepower for drive efficiency. (Divide BHP by 0.85 or 0.95 depending on drive used.)

6. For internal combustion engines divide the figure obtained in part 4 or 5 by the continuous service factor. (Check with engine manufacturer's specifications on this point. For purposes of estimation, a continuous service factor of about 0.75 to 0.80 can be used.) This will be the minimum rated horsepower required of the engine.

7. Estimate the cost of pumping for at least two types of power units and make selection on basis of economy, availability of power or fuel, and dependability of dealer service.

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DEFINITION OF TERMS

Irrigation Efficiency: The percentage of irrigation water pumped that is available in the soil for use by the crops.

Pump Capacity: The quantity of water a pump will deliver usually expressed in gallons per minute (gpm).

Total Head: The total head against which the pump operates consists of the following items:

Suction lift: Vertical distance in feet from the center line of the pump to the water surface.

Difference in elevation: vertical distance from center line of the pump to the point of discharge.

Friction loss: Loss in head or pressure caused by the resistance to the flow of water through pipe and fittings.

Discharge pressure: The head or pressure required at the discharge nozzle. If the pump has a free discharge this will be zero.

Pump Efficiency: The ratio of the theoretical power, or water horsepower, to the actual power required to operate the pump.

Brake Horsepower: The actual power required to run the pump. It is directly proportional to the pump capacity and total head and inversely proportional to the pump efficiency.

Acre-inch: An acre-inch is the amount of water required to cover one acre one inch in depth.

CONVERSION FACTORS

1 cubic foot per second (cfs) = approximately 450 gallons per minute (gpm)

1 cfs = approximately 1 acre-inch per hour

1 acre-inch = 27,154 gallons

1 pound per sq. in. pressure = 2.31 feet of head

1 foot of head = 0.433 pounds per sq. in. pressure

1 horsepower = 0.746 kilowatts

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